(12) UK Patent Application (19) GB (11) 2 196 432 (13) A

(43) Application published 27 Apr 1988

(21) Application No 8722484

(22) Date of filing 24 Sep 1987

(30) Priority data
(31) 3635207 (32) 16 Oct 1986 (33) DE

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(51) INT CL⁴
G01L 3/10

(52) Domestic classification (Edition J):
G1N 1D12 1D3 1M1 7J AEM
U1S 2171 G1N

(56) Documents cited
None

(58) Field of search
G1N
Selected US specifications from IPC sub-class G01L

(54) A device for the contactless indirect electrical measurement of torque in a shaft

(57) A device for the contactless indirect electrical measurement of the torque in a shaft (2) utilising the Matteucci effect is described. The shaft (2) is located in an induced magnetic direct-axis field ϕ produced by permanent magnets 1.1.2, 1.1.3 and a magnetic yoke 1.1.1. Upon torsion of said shaft, the change in magnetisation of a magneto-strictive, amorphous measuring layer (2.1) applied to the shaft is metrologically detected. In order to avoid disturbing influences from the basic magnetisation of the shaft (2) on the measuring layer (2.1), a further layer (2.3) of high magnetic permeability is applied to the shaft, which short-circuits the magnetic flux resulting from the basic magnetisation, the measuring layer (2.1) being magnetically decoupled from the inner layer (2.3) by a highly non-magnetic layer (2.2). The sensor 1.2 consists of a core 1.2.1 and a coil 1.2.2 which is energised e.g. at 100 kHz by a circuit 3.1. The inductance of coil 1.2.2 changes with the shaft torque.

There may be two sensors on opposite sides of the shaft and connected to a single evaluating circuit.

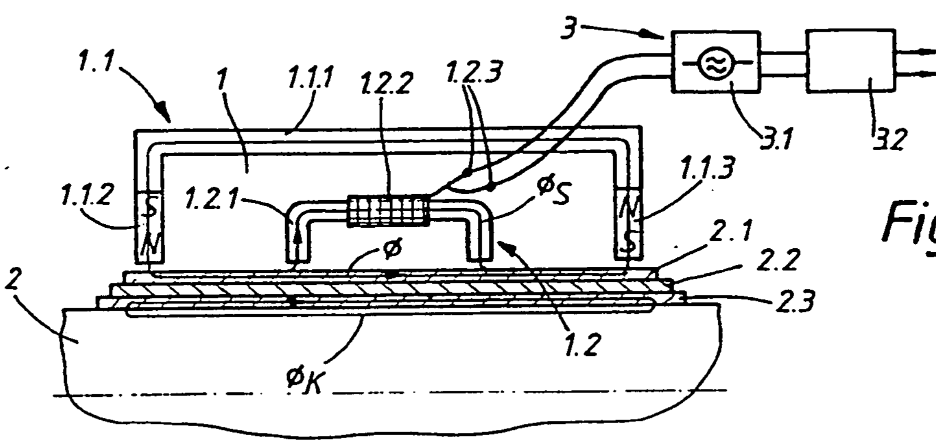

Fig. 1

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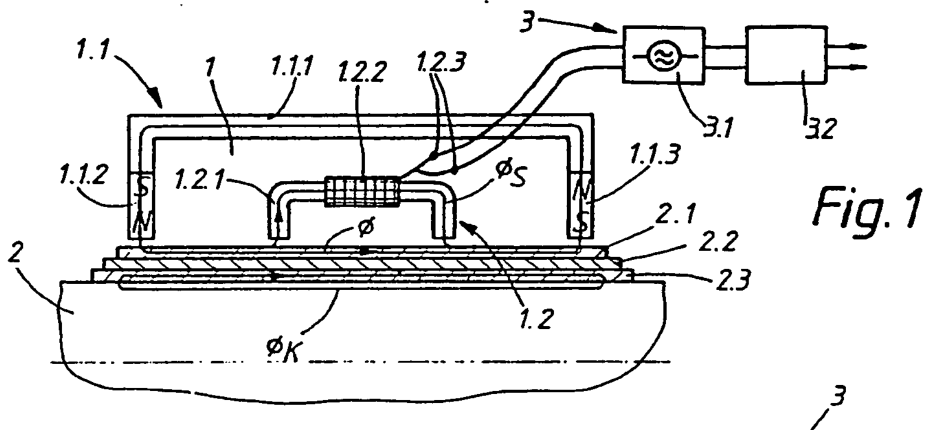


Fig. 1

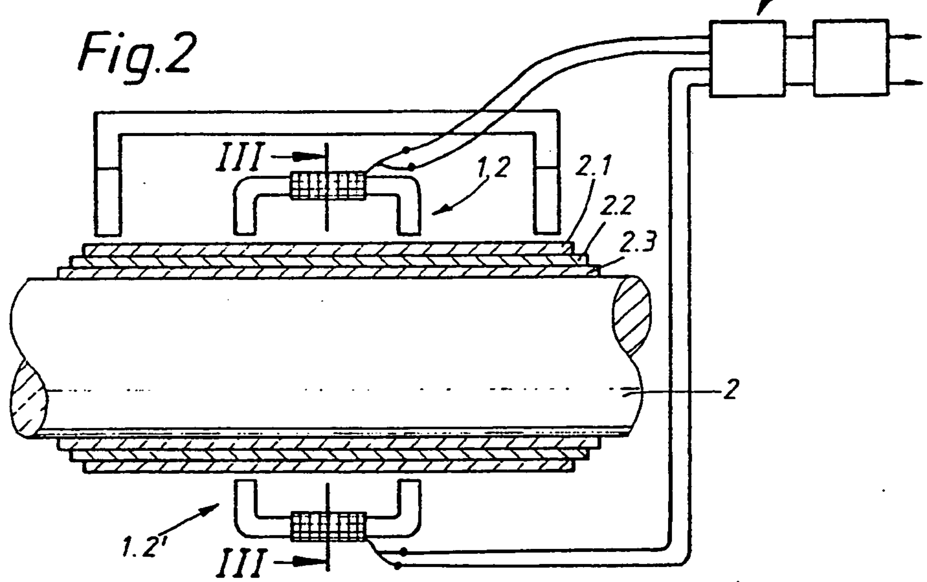
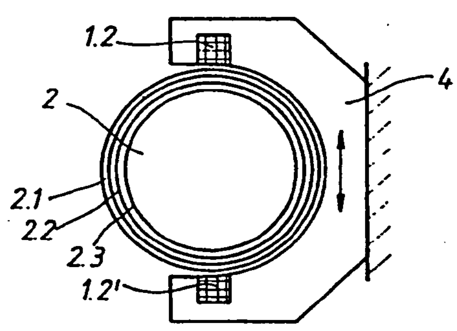


Fig. 2

Fig. 3



SPECIFICATION

A device for the contactless indirect lectrical measurement of torque in a shaft

The invention relates to a device for the contactless indirect electrical measurement of torque in a shaft, the device including a sensor arrangement located in proximity to the shaft and an evaluation circuit, the shaft being provided with at least one magnetic coating in the region of the sensor arrangement, with which the mechanical stresses proportional to the torque to be transferred can be sensed at a rotating, in particular a soft magnetic shaft.

Every soft magnetic material, for example that of a shaft, has a greater or lesser basic magnetisation, depending on its mechanical pre-history. This basis magnetisation changes, inter alia, under mechanical loading, and with the aging of the material. So if, utilising the "Matteucci effect", according to which a ferromagnetic rod located in an induced magnetic direct-axis field changes its magnetisation upon torsion, these changes in magnetisation were to be detected with the aid of a corresponding magnetic field sensor system, in order in this way to arrive at statements with respect to the mechanical stresses occurring in the shaft, these statements would have to be assessed appropriately relativised as they may be, or are, influenced and falsified by the basic magnetisation itself and the indefinite change in the basic magnetisation of the material of the shaft.

German Laid-Open Specification DE. OS 2316344 discloses a device in which a layer of non-magnetic material is applied to a soft magnetic shaft, and to this layer in turn a layer with good magnetostriction properties is applied. The non-magnetic layer in this case has to fulfil the purpose of insulating the shaft magnetically from the outer layer, through which the entire magnetic flux is to be conducted, which flux is generated by an alternating current-fed magnetising coil and a change in magnetic flux being detected by a detector coil on the transformer principle. Although an insulation is provided here between the applied measuring layer and the shaft, the instable basic magnetisation of the shaft under dynamic loading still leads to a falsification of the measured result since the magnetic field of the magnetised shaft also strays into the measuring layer.

The invention seeks to provide a contactl ss indirect electrical torque measurement of a shaft arranged in such a way that unfalsified measuring signals which are reliable and stable in the long term are obtained even in continuous operation under high mechanical alternating loads and under physically and chemically aggressive ambient conditions.

According to the invention there is provided a device for the contactless indirect electrical measurement of the torque at a shaft, comprising a sensor system which is located in proximity to the shaft and consists of a U-shaped magnetic field generator and at least one sensor having a core and a coil with electrical connections, and an evaluation circuit in which the sensor is in integrated by means of said connections, and comprising on the other hand coatings fixed on the shaft in the region of the sensor system, a highly soft magnetic, magneto-strictive amorphous first layer causing the magnetic direct-axis field generated by the magnetic field generator to be conducted in the longitudinal direction of the shaft for the completion of a magnetic circuit, which first layer is applied to an underlying, highly non-magnetic second layer, and the sensor being arranged in the area of the direct-axis field conducted through the fist layer and, upon torsion of the shaft, detecting a change in magnetisation in the first layer in the form of a change of the magnetic flux in its core, wherein the second layer is arranged on a highly permeable but nonmagnetostrictive, amorphous third layer applied directly on the shaft, the core, which is also in the magnetic circuit, of the sensor consists of nonmagnetostrictive amorphous metal, and the magnetic field generated by the magnetic field generator is a direct-current field, which is superimposed on the alternating-current field generated by the excited coil, a change in the magnetic flux effecting a change in the dynamic permeability of the core by means of a non-linear function of the magnetisation curve and as a consequence of the inductance of the coil, which change is converted in the evaluation circuit into a torsion-analogous electrical signal.

In one embodiment of the invention, a further sensor is arranged in proximity to the shaft, diametrically opposite to the first-mentioned sensor and is likewise integrated in the evaluation circuit by means of its electrical connections.

In another embodiment of the invention, the two sensors are mounted in a carrier which is displaceable in the vertical direction.

In yet another embodiment of the invention, the three layers are applied to the shaft by a chemical deposition process of nickel and a fraction of a metalloid - such as phosphor—or several factions of various metalloid, the phosphor fraction or the fraction of the other metalloids being varied from layer to layer during the deposition process.

Embodiments of the invention will now be described in more detail below by way of example and with reference to the accompanying drawing, in which:

Figure 1 shows, in a diagrammatic representation, the arrangement of the device;

Figure 2 shows, in a diagrammatic representation, a second embodiment of the device, and

Figure 3 shows a side view taken on the

line III-III in Figure 2.

The principle of operation of the device is based on the known Matteucci effect; which is that if a soft magnetic rod located in a magnetic direct-axis field is twisted, its magnetisation changes. With reference to Figure 1, the device comprises on the one hand a sensor system 1 and on the other hand coatings 2.1, 2.2 and 2.3 arranged on the soft magnetic shaft 2—the object of measurement.

The sensor system 1 consists in particular of a U-shaped magnetic field generator 1.1 extending in the longitudinal direction of the shaft 2 and formed by a Ushaped soft magnetic yoke 1.1.1 with permanent magnets 1.1.2 and 1.1.3 arranged at the ends of its arms facing the shaft, and a sensor 1.2, which has a U-shaped core 1.2.1, which lies within the yoke 1.1.1, is of a nonmagnetostrictive amorphous metal and whose arm ends likewise face the shaft and whose cross-piece bears a coil 1.2.2 with electric connections 1.2.3, which are connected to an evaluation circuit 3. Both the permanent magnets and the arm ends of the core are arranged a short distance from the shaft. The shaft 2 bears coatings in the active area of the sensor system 1—in other words somewhat beyond the permanent magnets in the longitudinal direction of the shaft—a highly permeable, non-magneto-strictive, amorphous third layer 2.3 being fixed directly on the shaft 2 on which third layer in turn a highly nonmagnetic second layer 2.2, and on this in turn a highly soft magnetic, magneto-strictive, amorphous first layer 2.1 are fixed; it goes without saying that the layers surround the shaft over its entire circumference.

The third layer 2.3 fulfills the purpose of short-circuiting the basic magnetism of the shaft 2 in the active area of the sensor system, so that the magnetic flux O_k resulting from the basic magnetism can only run within the shaft and the third layer 2.3.

The second layer 2.2 is for the magnetic decoupling of the third layer 2.3 and the first layer 2.1, while the first layer 2.1 represents the actual measuring layer.

As can be seen from Figure 1, a magnetic direct-current field is generated by the magnetic field generator 1.1 and is introduced into the first layer 2.1 (flux O), so that the magnetic circuit is completed in the longitudinal direction of the shaft. If the shaft 2—and with it the layers—is then twisted, in the layer 2.1 there is a change in its magnetisation state, which results in a change in the magnetic flux O. As the core 1.2.1 of the sensor 1.2 is likewise in the magnetic circuit, a change in the magnetic flux O also results in a change in the magnetic flux Os in the core of the sensor, to be precise, in the following respect: the coil 1.2.2 of the sensor is fed by a voltage source 3.1 of the evaluation circuit 3 at a constant frequency—for example an oscillator at 100 khz—whereby a certain alternating-current field is generated in the sensor and the core of the sensor is controlled to saturation. Superimposed on this alternating-current field is a direct current field component of the magnetic field generator, so that change in the magnetic flux O resulting from the direct-current field also induces a change in the magnetic flux Os—to be precise related to the direct-current field componentin the core. This change in the magnetic flux Os effects in the core 1.2.1, via the non-linear function B= f(H) of the magnetisation curve, a change in its dynamic permeability (H) = db/dH, and consequently a change in the inductance L of the coil 1.2.2 which can be evaluated in a signal conditioning stage 3.2 of the evaluation circuit 3—for example a simple oscillator electronics unit—in such a way that representation of an electrical voltage or frequency as a function of the torque is achieved.

In contrast to the embodiment shown schematically in Figure 1, in the embodiment illustrated in Figures 2 and 3, in addition to the sensor 1.2, there is also a further, diametrically opposed sensor 1.2′ arranged beside the shaft 2, both sensors being connected by their connections to the evaluation circuit 3. In this arrangement, the signals generated by the sensors are electronically added. These measures have the effect of allowing the oscillations of the shaft in the radial direction and thereby resultant magnetic flux changes to be eliminated, while the useful signal is doubled.

Since—as can be seen in particular in Figure 3the sensors are arranged diametrically opposite each other and in a vertical direction, small oscillations of the shaft in a horizontal direction do not have any effect on the signals generated by the sensors, since the air gap between the sensors and the shaft remains virtually constant.

If the sensors are also held by a carrier 4 which is displaceable in the vertical direction, a null balance with respect to the signals generated by the sensors is possible.

As far as the design of the sensor 1.2 and 1.2′ is concerned, it must be pointed out that its scarcely temperature-dependent inductive resistance is chosen many times greater than its temperature-dependent ohmic resistance, a copper wire having a small thermal resistance coefficient—for example, that known by the name "Thermosyn"—preferably being used for the sensor coil, whereby possible temperature drifts can be kept very small.

In the simplest case, the layers 2.1—2.3 can be three thin films—thickness approximately 20—50 m joined to the shaft and to one another by an adhesive technique or by explosive welding. However, it is also possible to obtain the said sequence of layers with their specified physical properties by various chemical or physical processes—such as evaporation coating, sputtering, tc. or electrolytic

depositions or chemical deposition reactions—or a combination of chemical coating process and physical process.

A chemical deposition process of nickel with a certain fraction of phosphor appears to be particularly advantageous, the control of the phosphor fraction allowing layers to be produced which range in their magnetic properties from highly soft magnetic to highly nonmagnetic. With this process, it is then possible, by changing just a few parameters in the chemical deposition, to apply all three layers to the shaft successively. The molecular intermeshing of the individual layers means that no change in the mechanical and magnetic properties is expected under high dynamic loading over a very long time and a high adhesion of the layers on the shaft and to one another is achieved. In addition owing to their surface structure, these layers have no corrosion tendency, so that the magnetic and mechanical properties of these layers are stable for a very long time for this reason as well.

Thus, the invention enables a torque measuring device to be constructed which has a simple, sturdy mechanical design, which functions reliably and stably in the long term even in continuous operation under high mechanical alternating loads and under physically and chemically aggressive ambient conditions, and which makes it possible to process further the signal generated by the sensors in a simple, inexpensive electronic signal conditioning unit.

CLAIMS

1. A device for the contactless indirect electrical measurement of the torque at a shaft, comprising a sensor system which is located in proximity to the shaft and consists of a U-shaped magnetic field generator and at least one sensor having a core and a coil with electrical connections, and an evaluation circuit in which the sensor is in integrated by means of said connections, and comprising on the other hand coatings fixed on the shaft in the region of the sensor system, a highly soft magnetic, magneto-strictive amorphous first layer causing the magnetic direct-axis field generated by the magnetic field generator to be conducted in the longitudinal direction of the shaft for the completion of a magnetic circuit, which first layer is applied to an underlying, highly nonmagnetic second layer, and the sensor being arranged in the area of the direct-axis field conducted through the fist layer and, upon torsion of the shaft, detecting a change in magnetisation in the first layer in the form of a change of the magnetic flux in its core, wherein the second layer is arranged on a highly permeable but nonmagnetostrictive, amorphous third layer applied directly on the shaft, the core, which is also in the magnetic circuit, of the sensor consists of nonmagnetostrictive amorphous metal, and the magnetic field generated by the magnetic field generator is a direct-current field, which is superimposed on the alternating-current field generated by the excited coil, a change in the magnetic flux effecting a change in the dynamic permeability of the core by means of a non-linear function of the magnetisation curve and as a consequence of the inductance of the coil, which change is converted in the evaluation circuit into a torsion-analogous electrical signal.

2. A device according to claim 1, wherein a further sensor is arranged in proximity to the shaft, diametrically opposite to the first-mentioned sensor and is likewise integrated in the evaluation circuit by means of its electrical connections.

3. A device according to claim 2, wherein the two sensors are mounted in a carrier which is displaceable in the vertical direction.

4. A device according to any one of claims 1 to 3, wherein the three layers are applied to the shaft by a chemical deposition process of nickel and a fraction of a metalloid - such as phosphor—or several factions of various metalloids, the phosphor fraction or the fraction of the other metalloids being varied from layer to layer during the deposition process.

5. A device for the contactless indirect electrical measurement of torque in a shaft, substantially as hereinbefore described and with reference to the accompanying drawing.

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